**1998 NACE Western Area**
**SSPC & Joint Military**
**Corrosion Conference**
**October 13-23**
**Honolulu, Hawaii**

# Use of New Generation Epoxy-Coated Rebar In the Admiral Clarey Bridge

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## INTRODUCTION

The design and construction of the Admiral Clarey Bridge exemplifies the use of reinforced concrete in a marine environment with a long performance life. Planners, designers, and builders must pay great attention to the many critical factors that ultimately contribute to the durability of the reinforced concrete. This paper provides a brief summary of some of the important concrete material issues related to performance with particular emphasis on supplemental corrosion protection using new standards for prefabricated epoxy-coated steel rebar.

**Construction of the Admiral Clarey Bridge, Pearl Harbor, Hawaii**

## THE ADMIRAL CLAREY BRIDGE

The Admiral Clarey Bridge connecting Ford Island to the Pearl Harbor Hawaii Naval Complex was dedicated April 15, 1998. The 4,700-foot long bridge is one of six reinforced concrete floating bridges in the world. The 650-foot moveable span is the longest in the world.

The request for proposals (RFP) for the design/build contract was developed with the assistance of a number of people and organizations. For the bridge concept, the RFP relied heavily on studies by the Pacific Division Naval Facilities Engineering Command's (PACNAVFACENGCOM) Planning Department. These included various Ford Island Access studies accomplished in 1987/88 and the Final Environmental Impact Study in 1990.

The RFP provided specific design criteria, which were developed mostly by PACNAVFACENGCOM's design engineers with assistance from the following:

- Naval Facilities Engineering Command, John Headland, Coastal Engineering.
- Washington State Department of Transportation, Myint Lwin, floating pontoon section and concrete.
- Federal Highway Administration, Raymond McCormick, highway/bridge.
- Naval Facilities Engineering Service Center (NFESC), Douglas Burke, prefabricated fusion-bonded pipeline-type epoxy-coated reinforcement.

Because rebar corrosion occurs much faster in a tropical environment, such as Hawaii, it was particularly important that emphasis be placed on the design of the concrete materials to provide long term durability. To maximize concrete durability, these design decisions were made:

- The use of 5 percent silica fume was recommended by Mr. Lwin based on his experience and success in using silica fume on the most recently constructed Washington State floating bridges.
- The use of a maximum allowable water-to-cement ratio (w/c) of 0.38 was based on waterfront engineering practices using locally available Hawaiian concrete materials.
- The use of a zero tension under service load criterion was based on the State of Hawaii Department of Transportation requirement for all bridges in Hawaii.
- The use of prefabricated fusion-bonded epoxy-coated rebar was a difficult decision to specify since the Navy's new standard was still under development by NFESC and the increased cost was uncertain. Ultimately, 4,600,000 pounds of epoxy-coated mild reinforcing steel was used to construct the bridge.

## COST/BENEFIT

For the Admiral Clarey Bridge a cost comparison of using plain steel rebar versus prefabricated epoxy-coated rebar was done. The predicted costs were $1.20/pound for plain rebar compared to $1.60/pound for coated rebar, installed. Therefore the additional cost amounted to ($0.40) x (4,600,000) = $1,840,000. Since the cost of the total project was $86 million, the premium to use this technology was 2.1 percent. This investment is expected to extend the rebar life by at least 20 years.

## EPOXY-COATED REBAR DEVELOPMENT

The decision to use epoxy-coated rebar in new Navy construction was based on extensive evaluations that began in 1984, when the Office of Navy Research tasked the Naval Civil Engineering Laboratory to conduct long-term field evaluations. Test specimens were suspended in a marine intertidal zone for 76 months at Key West, Florida to rank the relative performance of popular corrosion control methods. Damage-free epoxy-coated rebar performed best. Results from this study were presented by the Concrete Reinforcing Steel Institute in their Research Series 2 report of July 1994.

Despite the good performance in the Navy's long-term field tests, the Florida Department of Transportation and other agencies had found moderate to severe corrosion much earlier than expected on some marine structures using epoxy-coated rebar. By 1994, much controversy surrounded the use and performance of epoxy-coated steel reinforcing bars produced and placed in accordance with current specifications. Consequently, the Navy Criteria Office funded the NFESC to identify the failure mechanisms in current practices and to develop a new standard in cooperation with industry experts. This effort resulted in an Interim User's Guide for Prefabricated Epoxy-Coated Rebar for Oceans and Other Severe Environments (PROSE). The document included two new Navy Facilities Guide Specifications (NFGS), 03201 and 03202, and recommendations for a quality control program. The Navy Criteria Office identified candidate construction projects to incorporate the new generation of epoxy-coated rebar. Two Navy submarine piers were constructed, one in Pearl Harbor, Hawaii, and the other in New London, Connecticut. NFESC monitored the construction of each project and evaluated the cost and constructablity. Both projects proved highly successful and the differential costs were about 2 percent higher for each with respect to the overall construction cost. The toughness of the new epoxy powder formulation developed by 3M proved exceptionally good, requiring very few repairs after shipping, storage, and placement. The bridge also included small sections of epoxy-coated rebar coated with epoxy powder formulated by Akzo and O'Brien, which appeared to be equally durable.

The American Society of Testing and Materials (ASTM) used the Navy's draft specifications as a basis for the development of ASTM A 934/A 934M published in July 1995, “Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars.” Mr. D. Burke of NFESC is the current chairman of the ASTM Subcommittee A01.05 task group for development and revision of coated reinforcement standards. In February 1998, the NAVFAC Criteria Office published, for the first time, a definitive guide for Marine Concrete, NFGS 03311. Included is a requirement to use prefabricated epoxy-coated reinforcing steel according to the new ASTM Standard.


**Magnified View of Epoxy-Coated Rebar**

## IMPORTANT FEATURES FOR ENHANCED PERFORMANCE

There are many important features of the new technology for prefabricated epoxy-coated rebar contained in the ASTM Standard that contribute to improved performance. Some of these are:

- All of the rebar is prefabricated to final size and shape prior to coating. This avoids stress cracks in the coating and loss of coating adhesion in the bend areas during post fabrication, which has been a typical site for corrosion.

- Since the coating no longer needs to be flexible, new epoxy powder formulations can be used. These formulations are more durable and resistant to the intrusion of corrosive elements.

- Extensive quality control tests must be performed on every batch of coated rebar, including cathodic disbondment tests for coating adhesion. This requirement greatly reduces problems with underfilm corrosion.

- All visible defects in the coating must be repaired prior to concrete placement. This minimizes the number of locations in the barrier coating that might otherwise become corrosion sites.

In addition to the recommendations contained in the ASTM standard, NFESC strongly recommends that:

- Coated rebar is not mixed with plain rebar in the structure. This avoids the possibility of creating a large corrosion cell if there is electrical continuity between the coated and uncoated steel.
- Coated rebar should not be used in structures that are subject to large impact loads and in areas where the steel is severely congested (e.g., 50 percent or more of the cross section is steel). Because of the lack of adhesion of the cement paste to the epoxy coating, the concrete that covers the reinforcement may disbond when subject to impact loads, which was reported when a reinforced concrete component was accidentally dropped.

## CORROSION ACTIVITY

The purpose of providing supplemental corrosion protection, such as an epoxy coating, is to reduce the rate of rebar corrosion, thus increasing the time before corrosion related repairs are necessary. This is accomplished in two important ways:

- If the quality of the concrete is compromised in any manner that results in cracks, increased concrete permeability, or reduced concrete cover, then chloride, oxygen, and water will find their way to the rebar sooner than expected. An excellent barrier coating on the steel will extend the time before corrosion will take place.

- Eventually corrosive elements will reach the rebar regardless of the concrete materials used and the quality of the workmanship. When the chloride contamination reaches the threshold level necessary for the initiation of steel corrosion, the presence of a highly impermeable well-adhered barrier coating with a minimum number of defects will retard the potential for corrosion activity in the steel reinforcement.

## CONCLUSION

Concrete durability in a marine environment requires strict attention to many important aspects of planning, materials, design, and workmanship. Life performance of marine structures can be enhanced by the use of prefabricated epoxy-coated steel reinforcing bars with good coating adhesion and no visible damage to the coating. Construction of the Admiral Clarey Bridge exemplifies the use of these design and construction principles.

## OTHER PROJECTS USING EPOXY-COATED REBAR

Several projects within the Navy and in the private sector have used the new standards for prefabricated epoxy-coated rebar, such as, the Muni-Metro Turn Back in San Francisco, California and the Long Beach Aquarium in Long Beach, California. In 1998, the technology was reviewed and adopted by the California Department of Transportation (CALTRANS) for reinforced concrete structures within one mile of the coast.

**Construction of Muni-Metro Turn Back, San Francisco, California**

## ADDITIONAL INFORMATION

Additional information about the design and construction of the Admiral Clarey Bridge is contained in an excellent and comprehensive article by Michael Abrahams and Gary Wilson featured in the PCI Journal July/August 1998 issue. For more information about the use of prefabricated epoxy-coated reinforcement, please contact Douglas Burke at 805-982-1055 or burkedf@nfesc.navy.mil.